ESTCP
Cost and Performance Report

(SI-0006)

CAMP AVA
SMALL CALIBER OPERATIONAL NOISE CONTOURS
PROPOSED MPMG - ORIGINAL LOCATION

Mayberry Township

| | Camp Ava | | Zone II (65 ADNL) |
| | Proposed MPMG Range | | Zone III (> 75 ADNL) |

0   1   2   4
Kilometers
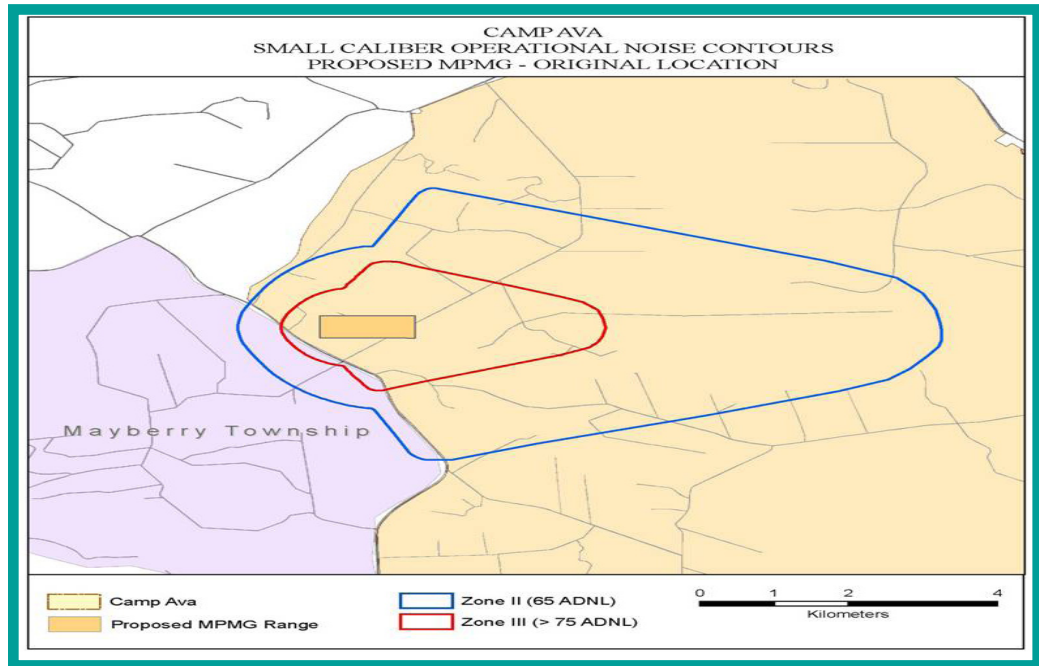
SARNAM™ Noise Impact Software

May 2008

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

	Report Documentation Page		Form Approved OMB No. 0704-0188

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COST & PERFORMANCE REPORT
ESTCP Project: SI-0006

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

ACS	Army Claims Service
ADNL	A-weighted day-night average sound level
ANSI	American National Standards Institute
AR	Army Regulation
ARNG	Army National Guard
ASEL	A-weighted sound exposure level
CERL	Construction Engineering Research Laboratory
CDNL	C-weighted Day-Night Average Sound Level
DA PAM	Department of the Army Pamphlet
dB	decibel
DNL	day-night level
DoD	Department of Defense
EA	Environmental Assessment
EIS	Environmental Impact Statement
EQT	Environmental Quality Technology
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
ETMP	Environmental Technology Management Plan
FICUN	Federal Interagency Committee on Urban Noise
GUI	graphical user interface
IL ARNG	Illinois Army National Guard
INMP	Installation Noise Management Program
Leq	equivalent continuous noise level
MPMG	multi-purpose machine gun (range)
mm	millimeter
NEPA	National Environmental Policy Act
NMPlot	noise map plot (software application)
ONMP	Operational Noise Management Plan
QA/QC	quality assurance/quality control
R&D	research and development
RFMSS	Range Facility Management Support System
ROI	return on investment

SARNAM™	Small Arms Range Noise Assessment Model
SE	sound exposure
SEL	sound exposure level
TES	Threatened and Endangered Species
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine

ACKNOWLEDGEMENTS

Technical material contained in this report has been approved for public release.

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1.0   EXECUTIVE SUMMARY

1.1   BACKGROUND

Weapons noise compromises the Department of Defense's (DoD) ability to maintain access to resources necessary for military training and testing. Community reactions to excessive military noise include complaints, damage claims, legal action, political pressure, and other efforts to curtail the noisy activity. Noise concerns have prompted installations to relocate training, impose firing curfews, and close ranges. Such short-term-solution decisions, if made without reliable noise management technology, can needlessly hamper training mission execution and ultimately impact soldier proficiency and survival. Noise impact assessment software can guide planning decisions to minimize noise impacts on soldier and civilian health and welfare. Impulsive noise from weapons training and testing is not governed by national laws; consequently, noise management consists of striking a balance between mission execution and environmental quality. Reliable guidance regarding noise level reduction under a wide range of conditions is arguably more important than the absolute accuracy of noise level predictions for specific conditions.

The military noise impact assessment software, or noise model, known as SARNAM™ enables calculation and display of noise contours for small arms ranges. The name SARNAM™ is an acronym for Small Arms Range Noise Assessment Model. Input options include the type of weapon and ammunition, number and time of shots, range size and structure, noise dose metrics, and assessment protocols. The model accounts for muzzle blast and projectile sonic boom spectrum and directivity, which facilitates accurate sound level prediction and interpretation of receiver response. SARNAM™ noise level predictions are based on the mean expected value of noise level metrics for mild downwind sound propagation conditions; this calculation is used in all directions, which moderately over-predicts noise levels in some regions. SARNAM™ is most useful as an environmental planning tool to address unwanted noise as an environmental attribute in the community; it can be used to avoid siting new noise-sensitive land uses in areas impacted by military noise and to guide mitigation of environmental impacts of operational plans or new facilities. Implementation cost of this Army in-house-developed software consists essentially of learning to use the software, which is facilitated by expertise in acoustics and familiarity with military weapons systems.

1.2   OBJECTIVES OF THE DEMONSTRATION

The overall goal of this project was to validate and demonstrate the SARNAM™ small arms noise impact assessment software under typical conditions. The objective of the "validation" aspect of the project was to test the accuracy of SARNAM™ by comparing calculation results with comprehensive noise monitoring data to judge noise level prediction accuracy. The objective of the demonstration aspect of the project was to evaluate the software utility and cost during realistic noise management consultation. The software was used to predict noise contours associated with the operation of a proposed new range and was then used to explore revisions to the range location and design to reduce the noise level in the adjacent community. The primary performance measures were the amount of noise dose reduction, the cost of use, and the projected cost savings.

1.3 REGULATORY DRIVERS

Department of the Army Pamphlet (DA PAM) 200-1 (2002) stipulates requirements and procedures for assessing training noise impacts. Noise contours are required for an Operational Noise Management Plan (ONMP) mandated by Army Regulation (AR) 200-1 version published in 1997 and revised in 2007. The National Environmental Policy Act (NEPA) requires assessment of impacts of proposed actions; implemented by Department of the Army 32 Code of Federal Regulations Part 651 Environmental Analysis of Army Actions: Final Rule. Noise is often one of the primary issues. A highly ranked Army Environmental Quality Technology (EQT) research and development (R&D) requirement, *Training and Testing Range Noise Control*, is a major requirement for this project. Another highly ranked Army EQT requirement, *Impact Protocols for Military Operations on Threatened and Endangered Species (TES)*, identifies noise as one of three impacts of particular concern. Regulatory drivers include the Endangered Species Act of 1973, as amended, the NEPA of 1970, as amended, the Sikes Act of 1995, and the Marine Mammal Protection Act. The software complies with applicable noise assessment practice promulgated by the American National Standards Institute (ANSI).

1.4 DEMONSTRATION RESULTS

This project had two primary aspects: validation and demonstration. The purpose of the validation aspect of the project was to verify the accuracy of SARNAM™ noise contour calculations. The project also resulted in information regarding how best to employ the software. Each element of the application, particularly calculation algorithms, had been validated under controlled conditions prior to the present project. This project planned to test the combination of all elements under actual conditions by measuring community noise levels in training scenarios at a military installation during an entire year, then comparing the measured levels with SARNAM™ calculated results. The goal of agreement within 5 dB was not met for several reasons. The monitoring period was cut short by an unexpected closure of the ranges, and only summer, not the typically more noisy winter weather conditions were sampled. Analysis of the data pointed up the critical consequences of inaccurate range firing data for determining metric values, particularly annual averages. The results of the validation support the need for an option in SARNAM™ to select among a variety of weather classifications, rather than the current downwind-only model, to achieve improved accuracy under more well-defined weather conditions. The results emphasize that, given the always-present uncertainties in propagation conditions and operation parameters (e.g., weapon, location, and number of shots) that influence sound level predictions, it is not reasonable to expect agreement between predictions and spot measurements. The software is very useful in determining the effects of changes in facilities and operations; these effects are valid regardless of uncertainties and ephemeral conditions.

The demonstration aspect of the project evaluated the utility of SARNAM™ in dealing with realistic operational noise problems. The software was used to assess the noise emission from a proposed new firing range and to explore and evaluate options to reduce community noise impact. Options were identified that provided 5- to 10-dB reductions, which exceeded the goal of a 5-dB reduction, by moving the range location and adding noise barriers. Prior to SARNAM™, the only way to assess small arms noise impact was by manual hand calculation of the expected noise environment in combination with on-site noise monitoring. SARNAM™ was shown to reduce the labor and cost of small arms noise analysis by 65%, which significantly exceeds the

20% cost reduction goal. SARNAM™ was demonstrated to be an effective means for reducing community noise to maintain combat training throughput.

1.5   STAKEHOLDER/END-USER ISSUES

The primary end user is the USACHPPM Operational Noise Program, the group that provides blast noise consultation to all of DoD for both large and small arms. Other users include private sector consultants who perform noise assessments for installations. All of them are concerned about software accuracy, implementation cost, cost savings, and ease of use. The Army developed the SARNAM™ software in house, so there are no proprietary considerations. Implementation cost consists essentially of learning to use the software, which is facilitated by familiarity with acoustics and military weapons systems. SARNAM™ cost savings enable USACHPPM to provide faster and more accurate cost-effective noise control consultation to a larger number of DoD installations to protect and facilitate combat training mission capability.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

The SARNAM™ software application provides the capability to calculate and display noise level contours for small arms range firing operations involving military and commercial weapons. All DoD Services rely on SARNAM™ to model small arms blast noise, and the software is also useful at law enforcement and recreational shooting ranges. The software is designed to enable installations to carry out some noise management tasks and calculations themselves. Since specialized expertise is required to execute some aspects of blast noise assessment, installations can take advantage of USACHPPM expertise and experience to complete complex or critical noise studies for purposes such as the ONMP and the National Environmental Policy Act (NEPA).

The architecture of SARNAM™ is shown in Figure 1. The software consists of three program modules: the graphical user interface (GUI), the DOCALC calculation engine, and the noise map plot (NMPlot) contour display application. The information that the user enters via the GUI is written to a case file and handed to the calculation engine. The data calculated by the engine is written to the NMBGF file and handed to NMPlot for fitting and display of noise contours. SARNAM™ features a point-and-click graphic user interface, pull down menus, and online help—all designed to maximize user productivity (Pater et al., 1999).
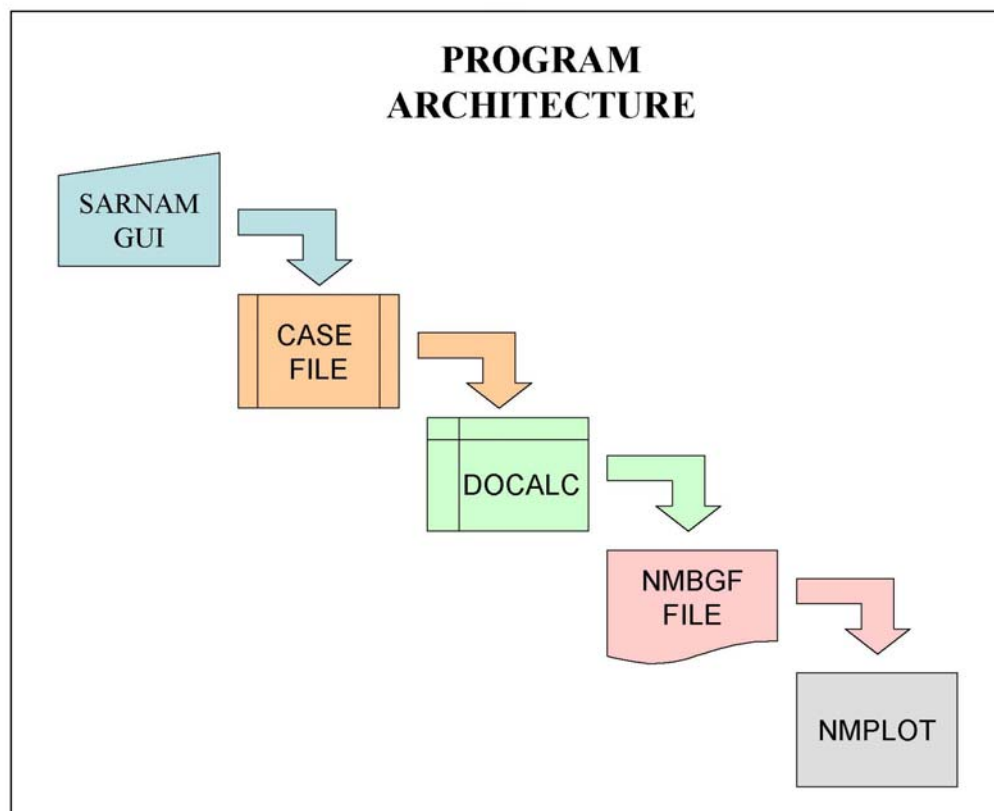

Figure 1. SARNAM™ Architecture and Process Diagram.

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To make a run, the user first creates an activity file that specifies the weapons, the locations at which they are fired, range attributes such as size and barriers, and the number of shots during daytime and nighttime. Options chosen from pick lists include the weapons, sound exposure metrics, frequency weightings, and assessment procedures that are appropriate for small arms noise (Hede and Bullen, 1982; Luz et al., 1983; O'Loughlin et al., 1986; Sorenson and Magnusson, 1979). A sound source emission model for each weapon, based on experimental measurements and included in a source database within the software, is the starting point for propagation calculations. A propagation algorithm is used to calculate sound levels at each node of a user-defined geographical grid. The resulting grid array of noise level values is converted to contours and prepared for display by the NMPlot software developed by the U.S. Air Force. Both the propagation algorithm and the source models enable consideration of spectrum and directivity of muzzle blast (Pater, 1981) and projectile bow shock, which facilitates accurate calculation of propagation attenuation and barrier insertion loss.

Received sound level depends greatly on atmospheric propagation conditions (Schomer and Luz, 1978). Sound propagation velocity in the atmosphere is determined primarily by temperature and wind velocity (speed and direction), with second-order dependence on relative humidity and barometric pressure. These parameters vary with time and with height above the ground, particularly near the earth in what is termed the boundary layer and at higher altitudes at an inversion layer. The resultant variation of sound propagation velocity with altitude causes sound to refract in much the same way as a lens refracts light. Experience during this and previous investigations has provided information regarding the degree of variation in received sound level for small arms. With a calm, clear day as reference, measurements have shown that even a moderate breeze can cause about a 5-dB increase downwind and a decrease of as much as 15 dB in the upwind direction (Pater, 1992; Pater et al., 1994). Overcast versus sunny conditions have a large effect that results from solar radiation heating the ground surface and affecting air temperature near the ground. Prevailing weather conditions and ground cover will cause sound levels to generally be substantially louder in winter than in summer. The authors have also measured variations of as much as 30 dB during a time period of only a few minutes, probably due to atmospheric turbulence (Pater, 1981). To put these variations into perspective, a 10-dB increase represents roughly a doubling in subjective loudness for many types of noise (Crocker, 1998).

The calculation algorithms used in SARNAM™ were previously verified to be accurate under known propagation conditions, as described in Section 2.3, Previous Testing of the Technology. Budget reductions during SARNAM™ development prevented detailed accounting for the full range of weather effects. SARNAM™ sound level predictions were therefore based on a single weather case, chosen to yield a reasonable approximation to expected average propagation conditions. The SARNAM™ propagation algorithm predicts the mean expected value of noise level metrics for mild downwind conditions. This calculation is used in all directions, which moderately overpredicts noise levels in some regions since the wind cannot be blowing in all directions at any one time.

2.2   PROCESS DESCRIPTION

This project was jointly executed by ERDC/CERL, the developer, and USACHPPM, the primary user. The validation aspect of this project tested the accuracy of the SARNAM™ application by

comparing calculations with noise monitor data obtained under actual training conditions at an Army facility. The demonstration aspect of the project evaluated the utility of SARNAM™ in dealing with realistic installation noise management problems under operational conditions. The software was used to assess the noise footprint for a proposed new range, then used to explore revisions to reduce the community noise dose. The primary performance measures were the amount of noise dose reduction effected by using the software, the cost of use, and the cost savings.

2.3   PREVIOUS TESTING OF THE TECHNOLOGY

Considerable testing of the software elements occurred before this current validation and demonstration project. The assessment procedures, metrics, and frequency weightings follow ANSI standards (ANSI S1.1 2004, ANSI S1.4 2001, ANSI S12.9 Pt.1 2003, ANSI S12.9 Pt. 4 2005). The software uses, as the starting point for noise level predictions, an acoustical emission (source) model that is based on careful measurements for each weapon (Pater, 1981, and unpublished data). The propagation algorithms that are used to predict noise levels (Gilbert and White, 1989; White and Gilbert, 1989; Li et al., 1994; White and Li, 1996) were verified by comparison with experimental data under known atmospheric propagation conditions (White, 1994). SARNAM™ small arms sound level predictions have been compared with single event measurements with good agreement (unpublished data). USACHPPM began to use the beta version of the software immediately to deal with a backlog of small arms consultations, so had considerable experience in using it before this current project. The current project was designed to test SARNAM™ under realistic, uncontrolled conditions that are encountered in typical noise management efforts at installations.

2.4   ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

SARNAM™ is the only software available in the United States for assessment of small arms range noise. Before this software, small arms noise analysis consisted of expensive on-site measurement that sampled only a limited time period supplemented by hand-calculated estimates, the quality of which depended on the consultant's knowledge of an esoteric field. The capability to quickly produce noise contours and to evaluate alternative noise mitigation strategies offers many benefits. SARNAM™ is highly useful as effective support of an environmental planning process as required by DA PAM 200-1 (2002). Given the always-present uncertainties in propagation conditions and operation parameters (e.g., weapon, location, and number of shots) that strongly influence sound level predictions, good agreement between predictions and spot measurements is not a reasonable expectation. Accuracy of predicted sound level ultimately depends not only on accurate source models and propagation algorithms but also on accurate knowledge of actual sound speed profile, type and location of weapon, and number of shots. The software is most effective for reliable determination of the effects of changes in operations or facility location and design, which provides extremely useful noise impact management guidance regardless of momentary uncertainties.

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3.0   DEMONSTRATION AND VALIDATION DESIGN

3.1   PERFORMANCE OBJECTIVES

The overall goal of this project was to demonstrate and validate SARNAM™ the small arms noise impact assessment software. The objective of the validation aspect of this project was to test the accuracy of SARNAM™ by comparing calculation results with comprehensive noise monitor data to judge noise level prediction accuracy. The objective of the demonstration aspect of the project was to evaluate the software utility and cost during realistic noise management consultation.

Validation of the software consisted of measuring noise levels in training scenarios, and comparing the measured results with the calculated results from the software, the obvious criterion being the degree of agreement. This was planned to be accomplished by measuring and recording noise levels at several locations and distances during normal training operations for an entire year, to sample a wide range of weather conditions. ERDC/CERL, the software developer, carried out the noise measurements, with assistance from installation personnel. USACHPPM, the primary user of the software, judged the validity of the noise software predictions by comparing them with the experimental data, and provided quality assurance/quality control (QA/QC), including oversight of the experimental data collection and analysis.

The primary performance measures of the demonstration aspect of the project are reduction in community noise exposure and cost. This was determined by USACHPPM and installation personnel by first using the noise software under consideration to assess noise exposure for operations as usual. The software was then used to execute additional assessments to explore community noise dose reduction options. Factors of importance include ease of use and cost performance.

Quantifiable performance objectives, as originally stated for this project, are as follows:

- Agreement between predicted and measured noise levels within 5 dB
- Enable a 20% reduction in community noise exposure in siting training activities
- Enable a 20% reduction in overall cost associated with noise impact assessment.

The goal of enabling a 20% reduction in community noise exposure bears further explanation and consideration. Noise is defined as unwanted sound. A reduction of 20% in sound exposure (SE) is a reduction in sound exposure level (SEL) of only 1 dB, while a larger 50% reduction in SE is a reduction of about 3 dB in SEL. An SEL reduction of 10 dB is required to achieve a 50% reduction in *perceived* noise level (Crocker, 1998), which implies that a 20% reduction in subjective noise exposure requires an SEL reduction of about 3-dB. While a 3 dB reduction in noise level can be useful, a 4- or 5-dB reduction in SEL or day-night level (DNL) is a traditional goal for a noise level reduction that is unarguably significant in terms of human perception of noise exposure. This more stringent noise reduction goal was adopted as the goal for judging SARNAM™ performance in this ESTCP demonstration project.

3.2   SELECTING TEST SITES/FACILITIES

The primary selection criteria for the validation site were sufficient firing activity, terrain suitable for carrying out noise measurements, and availability of adequate training records to guide noise model calculations. Site personnel must be willing to support and assist the project and provide contributions that leverage with ESTCP, ERDC/CERL and USACHPPM resources. The SARNAM™ software was validated at the Marseilles Training Area, a facility of the Illinois Army National Guard (IL ARNG), which was judged to meet all the criteria and was located close enough to ERDC/CERL that travel costs were reasonable.

The Marseilles Training Area, while ideal for validation, has minimal community noise problems. Another site was therefore chosen as the demonstration site to provide a useful example of how SARNAM™ can be used to reduce noise impact. This site is a major military training facility that will be referred to by the pseudonym "Camp Ava" to comply with installation directives regarding facility and operational security. This demonstration example is an actual noise mitigation consultation that was carried out by USACHPPM.

3.3   TEST FACILITY HISTORY/CHARACTERISTICS

SARNAM™ field validation was carried out at the Marseilles Training Area, an IL ARNG facility located in LaSalle County in north-central Illinois. The nearest town is Marseilles, which is 4 miles away. The pollution emission of concern, small arms noise, is generated by training exercises of the ARNG and local law enforcement entities. It is the primary training area for the IL ARNG. The Marseilles Training Area encompasses 2,552 acres, about 4 sq mi, and features four small arms ranges of various types located adjacent to the southern boundary of the installation. The installation terrain is generally rolling and wooded but is relatively flat and open in the vicinity of the ranges, a situation that facilitates noise measurement. The noise monitor sites were on ARNG property or on adjacent private property. A map of the entire Marseilles Training Area is shown in Figure 2. The small arms ranges are located in the southeastern portion of the installation, as detailed in Figure 3.

The SARNAM™ software application was demonstrated as part of a range planning and siting study for a multi-purpose machine gun (MPMG) .50 caliber range at Camp Ava. Specific distinguishing features of the installation and surrounding population distribution, particularly details of range location and function, have been modified at the installation's request to avoid compromising facility and operational security. The features shown in Figure 4 are faithful to the situation for purposes of demonstrating the use of SARNAM™ to achieve noise reduction. The facility is typical of many large installations in that it has been a major training facility for more than 50 years. It was initially located in a sparsely populated region, but communities grew up nearby to serve the needs of the installation; as they grew, they became less economically dependent on the installation, and increasing awareness of environmental quality led to a population less tolerant of the noise that is implicit in the operation of a combat training facility.
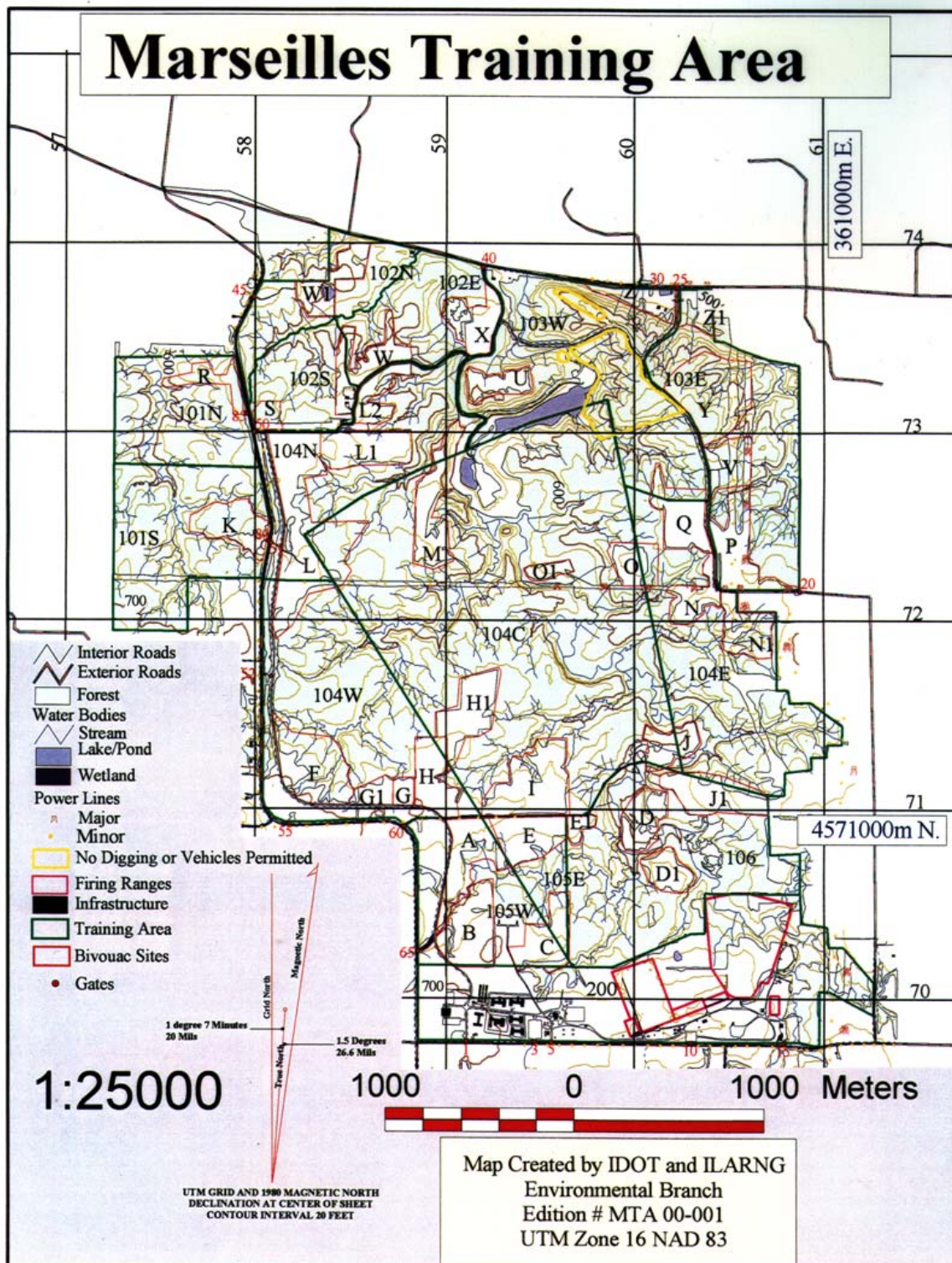
Figure 2. Illinois ARNG Marseilles Training Site Map.
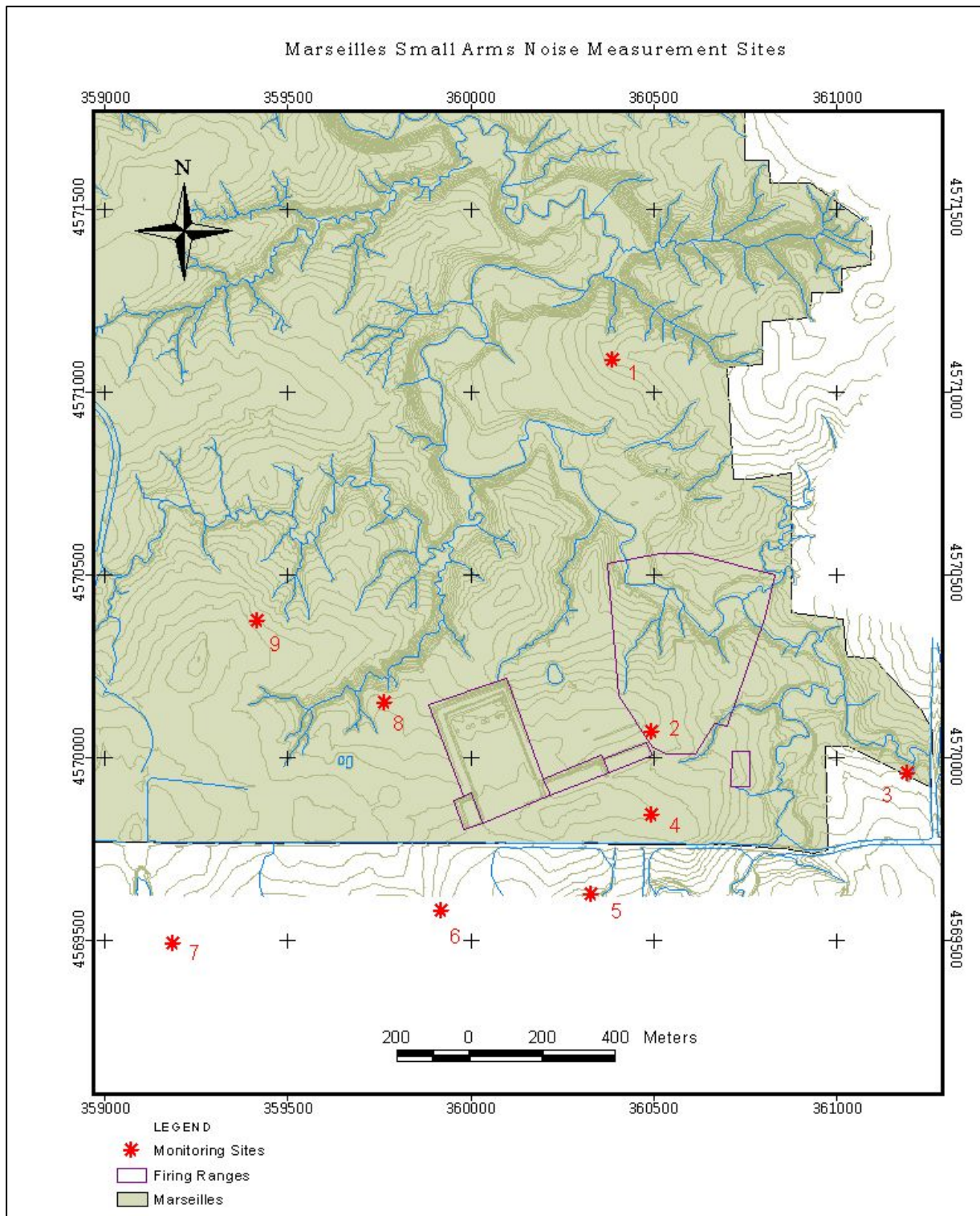
Figure 3. Small Arms Firing Ranges and Noise Monitoring Sites at Illinois ARNG Marseilles Training Site.
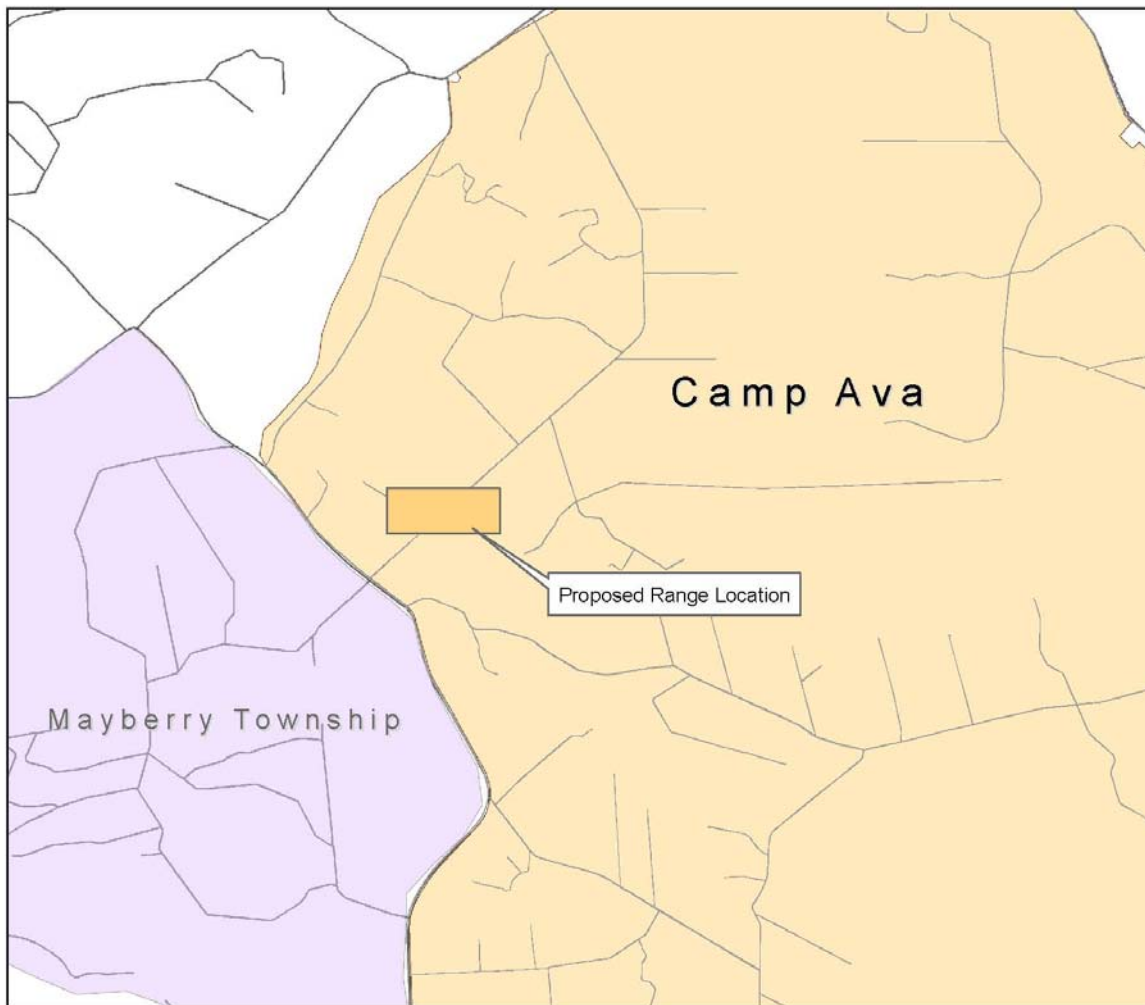
Figure 4. Camp Ava Range Location.

3.4   PHYSICAL SETUP AND OPERATIONS AT THE VALIDATION SITE

At Marseilles Training Area, 10 noise monitors were used, nine at monitoring sites located on the installation and on nearby private land, with one held in reserve as a spare in case of equipment malfunction or breakdown. The locations of the firing ranges and of the monitoring sites are shown in Figure 3. The noise monitors were located at sites chosen to sample noise levels at a selected variety of distances and directions relative to the small arms ranges, taking into account directivity of both muzzle blast and projectile sonic boom noise. The measurement site locations were dictated to an extent by terrain characteristics and by year-round accessibility.

3.5   SAMPLING/MONITORING PROCEDURES AT THE VALIDATION SITE

The primary sampling equipment was Norsonics[TM1] Model 121 noise monitors. These commercial off-the-shelf noise monitors were represented to be capable of untended operation over extended time periods and also capable of simultaneously and accurately measuring values of several appropriate blast noise metrics, particularly sound exposure level and peak (Hede and Bullen, 1982; Luz et al., 1983; O'Loughlin et al., 1986; Sorenson and Magnusson, 1979; CHABA, 1981; CHABA, 1996). An important feature of the monitors was the capability to make an audio recording of each noise event, enabling postprocess verification of the type of noise event measured. The monitors measured and recorded events that exceeded a preset trigger threshold, which after an initial period of trial and error, was set at 85 dB A-weighted-peak sound pressure level. This trigger level avoided a large number of false events due to wind blowing over the microphone, which would quickly fill up data storage space, and also avoided data contaminated by wind noise. Experience has shown that the threshold for receiving complaints about small arms noise is in the vicinity of 85 dB, so the most important events were captured.

The pollutant sampled was noise from typical small arms training operations. The known general characteristics of how the sound level varies in the field around the gun guided choice of the sampling sites. Sound energy emitted by a point source, such as the gun muzzle blast or projectile detonation, travels outward from the source on a spherical wave front. The gun muzzle blast is a strongly directive source that typically exhibits about 10- to 15-dB variation in source strength with azimuth (Pater, 1981). The sonic boom noise from supersonic projectiles exhibits additional directivity; it in fact exists only in a region downrange of the firing point, typically within an arc of about 60° on either side of the line of fire. Sonic boom noise spreads conically rather than spherically. All of these issues influence the optimum location for noise-level sampling.

The effect of weather on sound propagation yields large variations in received sound level. Weather can cause a variation in received noise level of as much as 50 dB at a given receiver location at larger distances. The monitoring locations were selected to sample the range of these variations at locations of greatest interest for assessing community noise impact. Because these models are for long-term average exposure and because of the prohibitive costs of collecting meteorological data, there was no detailed meteorological data collection or correlation with noise monitoring. SARNAM™ is intended to assess long-term average or total noise dose, or to forecast noise dose in the past or future when weather usually cannot be known with sufficient accuracy. The sampling plan was developed to use the entire range of the program capability, including muzzle blast noise and supersonic projectile noise. (There is no projectile detonation noise for small arms.) Random selection of sampling sites would be a less useful procedure. This project utilized noise events that occurred during actual training, consisting of hundreds of thousands of shots fired by the IL ARNG and law enforcement units. Data download was accomplished by changing out 1 GB microdrives.

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[1] Citing product or company names does not constitute endorsement by ERDC/CERL, USACHPPM, ESTCP, SERDP, or the U.S. Army.

3.6   ANALYTICAL PROCEDURES OF THE VALIDATION

The standard for monitoring, characterizing, and/or confirming technology performance is comparison of measured noise data with the software-calculated values. The assessment procedures were in accordance with the applicable ANSI standard (S12.40-1990) in effect at the time for annualized DNL noise impact assessment. As the name of the metric ("annualized") implies, this comparison was made for the entire monitoring period. Comparisons were also made of several sound level metrics, including single event metrics, on each day for which noise data was available, in terms of peak sound pressure level, total sound exposure level, and mean event sound exposure level.

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4.0   PERFORMANCE ASSESSMENT

4.1   PERFORMANCE DATA

Sound levels were monitored for validation purposes May 23-October 30, 2001. It was originally planned to measure throughout the winter and the following spring, but because of the September 11, 2001 terrorist attack, the IL ARNG closed the ranges for the remainder of 2001 and into 2002. Range records that reported date, weapons, firing range, and the number of rounds fired each day were obtained from Marseilles Training Site personnel. The range records indicated that more than 300,000 rounds were fired during the validation period, but close examination revealed discrepancies. There were days when the installation records indicated that firing had occurred, but the monitoring data did not detect any blast events, and also days when the records indicated no firing but shot noise events were recorded. Only those days when firing was verified by monitor data to have occurred were used in the validation process, which reduced the total number of rounds analyzed from more than 300,000 to about 166,000. A calendar of firing event data, including range, weapon, and number of rounds was compiled, then used to carry out SARNAM™ calculation runs. A detailed presentation of the range records, SARNAM™ calculations of noise level metrics, and measured values of noise metrics for each day used in the validation process as well as summary data for the entire validation period may be found in a report entitled "SARNAM™ Noise Impact Software Final Report" (Pater et al., 2007). Sample data are presented in Figures 5 and Table 1 of this current report, showing the summary data for the entire assessment period. Details and conclusions of the data analysis are discussed in Section 4.3, Data Assessment.

4.2   PERFORMANCE CRITERIA

The primary validation criterion that was specified in the demonstration plan before the project began was agreement between measured levels and calculated results within 5 dB. The primary performance measures of the demonstration aspect of the project are cost reduction of at least 20% and achievable reduction in community noise exposure of at least 4 dB (preferably at least 5 dB).

4.3   DATA ASSESSMENT

4.3.1   Validation Aspects at Marseilles Training Site

Judgment regarding the validity of the SARNAM™ software predictions was made by comparing SARNAM™ calculated noise metrics with the field measurements obtained via the Norsonics™ Model 121 noise monitors. The basic premise of the validation design was that it is appropriate to compare noise levels measured by instruments in the field with those predicted by the SARNAM™ noise model. There are several factors that complicate and can compromise the validity of such a comparison. These must be properly taken into account to reach meaningful conclusions and to refine optimal use of the noise model. This section describes the comparisons made, discusses potentially misleading comparisons, arrives at a measure of SARNAM™ validity, and discusses software improvements and optimizing use of the software.

All Ranges
All DAYS record

	site 1	site 2	site 3	site 4	site 5	site 6	site 7	site 8	site 9
■ SARNAM Unweighted Peak	94.9	128.7	94.8	111.2	105.0	112.6	89.7	109.7	100.5
□ Monitoring Event Mean APeak	88.8	96.3	87.7	91.8	89.4	89.3	87.5	91.3	89.5
■ Monitoring Event Max APeak	108.4	124.0	109.8	120.1	110.6	106.1	94.5	122.0	111.4
□ Monitoring Event Min APeak	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
■ LEQ (Monitoring Event & Amb.)	49.2	58.3	51.6	57.3	55.4	53.9	52.5	53.5	51.7
■ SARNAM ASEL Total	97.9	133.7	115.6	133.4	122.9	128.4	96.1	127.1	115.5
□ Monitoring ASEL Total	98.3	118.9	94.5	107.8	103.9	102.3	83.7	108.4	101.7
■ SARNAM Event ASEL	64.2	96.9	68.2	84.0	70.8	88.2	59.6	78.9	71.0
■ Monitoring Event Mean ASEL	60.0	67.1	58.9	60.8	61.7	62.2	58.9	63.1	60.8
□ Monitoring Event Max ASEL	75.0	93.2	76.1	85.4	78.7	77.9	69.2	91.1	78.4
■ Monitoring Event Min ASEL	47.9	41.7	44.7	29.9	49.3	34.6	51.4	48.7	38.2

**Figure 5. Graphical Presentation of Noise Monitor Data and SARNAM™ Predictions
for the Entire Assessment Period at Marseilles Training Site.**

18

**Table 1. Tabular Presentation of Statistical Variation of Noise Monitor Data
for the Entire Assessment Period at Marseilles Training Site.**

NOISE MONITORING DATA
Range A (5.56/7.62/9mm/45 cal/50 cal/12 guage/22 LR), Range B (5.56), Range C (5.56/9mm/45 cal/12 guage), Range D (9mm/45 cal/12 guage)
May 23 – October 30, 2001
310874 Rounds (Range Facility Management Support System [RFMSS])
Trigger 85 dBAPeak

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Number of monitoring events	4,339	40,732	1,881	21,155	9,393	5,709	243	13,666	7,426
Monitoring event mean A-peak	88.8	96.3	87.7	91.8	89.4	89.3	87.5	91.3	89.5
Standard deviation event A-peak	3.4	7.6	2.7	5.2	3.6	3.5	2.1	5.3	3.5
85-95	4,044	19,706	1,845	15,892	8,590	5,256	243	10,593	6,809
95-105	292	14,821	36	4,866	787	452	0	2,783	609
105-115	3	5,775	2	388	16	1	0	273	8
115-125	0	430	0	9	0	0	0	17	0
$\geq$125	0	0	0	0	0	0	0	0	0
Monitoring ASEL total	98.3	118.9	94.5	107.8	103.9	102.3	83.7	108.4	101.7
Monitoring event mean ASEL	60	67.1	58.9	60.8	61.7	62.2	58.9	63.1	60.8
Standard deviation event ASEL	3.8	6.7	4.1	5.2	4.4	4.5	2.7	5	4.3
40-50	5	10	5	42	5	2	0	2	43
50-60	2,273	5,588	1,263	10,222	3,625	1,878	168	4,036	3,169
60-70	2,018	22,577	547	9,773	5,392	3,519	75	8,194	4,079
70-80	43	10835	66	1100	371	309	0	1,398	134
80-90	0	1711	0	16	0	0	0	35	0
90-100	0	11	0	0	0	0	0	1	0
$\geq$100	0	0	0	0	0	0	0	0	0

Weapons noise impact assessment practice utilizes long-term average sound exposure levels, consistent with accepted practice for other types of noise such as transportation noise due to aircraft and highway traffic (Schultz, 1978). Because weapon impulse noise can vary so widely due to weather, average levels can be usefully supplemented by single event levels to better assess community noise impact and response, particularly regarding the likelihood of receiving noise complaints (Pater, 1976; Luz et al., 1983; Hede and Bullen, 1982; O'Loughlin et al., 1986; Sorenson and Magnusson, 1979). Thus both average and single event metrics were examined.

The SARNAM™-calculated results that were compared with the experimental data were based on the range records provided by the installation, excluding days for which the records were obviously incorrect (as discussed previously). The critical parameters are the weapon type, location, and number of rounds fired. The type of weapon is important because weapons vary considerably in acoustical emission magnitude and directivity. The location is important because the distance to each monitoring site is different for each range (actually, for each firing lane of each range). The number of firing events that occurred directly affects SARNAM™ predictions of average noise level metrics such as DNL and equivalent continuous noise level (Leq). It was not economically feasible to be on site every day of the monitoring period to verify the range records, so they are an uncontrolled variable in this project. USACHPPM has found through experience that range records of doubtful validity are virtually always a factor in gunfire noise consultations.

The number of noise events detected by each noise monitor cannot be expected to agree with the number of shots indicated by the range records; the noise monitors cannot discern individual gunshots but can measure only the highest peak level and the total SEL that occur during any 1-second interval. Many shots may be fired during a 1-second interval, especially if there are several shooters on the ranges. Also, only noise events that exceeded 85-dB A-weighted peak level were recorded, excluding many low-level events. The unavoidable conclusion is that the number of verified experimental "events" (1-second intervals during which gunfire occurred, verified as gunfire by listening to the audio clips) should always be fewer than the number of events indicated by the range records. There were 4 days when the reverse was true, clearly showing that the range records were not reliable.

The monitor summary data presented in Table 1 and Figure 5 provide the basis for observations regarding the experimental data; these are important as background to validation conclusions and also as information that guides the use of and interpretation of results from noise models. The first row of Table 1 presents the total number of 1-second intervals during which gunfire was detected. The fact that the number is not the same for all sites indicates that the statistical population is incomplete for many of the sites. The minimum A-peak value is 85 dB (the trigger level) for all sites, further indicating that the population is incomplete at all sites. Site 2 has the largest population (40,732 events), so the standard deviation values (7.6 dB A-peak, 6.7 dB ASEL) are presumably the most meaningful. For a Gaussian distribution, over 99% of all events are expected to fall within three standard deviations of the mean; for Site 2, this equals 45.6 dB in A-peak and 40.2 dB in ASEL. The maximum and minimum values of these variables at Site 2 differ by 39 and 51.5, respectively. The actual ranges are probably larger since low-level events were no doubt excluded. Causes of variations at any site include measurement error (believed to

be less than 1 dB), type of weapon, distance from source to receiver, and propagation (weather) conditions.

One possible comparison is peak sound pressure level of individual events at each measurement site. SARNAM™ calculates the largest expected value of unweighted mean peak level for each combination of weapon and location. For typical small arms impulsive pressure waveforms, A-weighted peak and unweighted peak are nearly identical since almost all the acoustical energy occurs in the portion of the spectrum that is minimally affected by the weighting filter. The effect of wind blowing over a microphone introduces low frequency "noise" into sound measurements; an A-weighting filter excludes most of the spurious signal fluctuations due to wind. Thus the most meaningful comparison that could be made was between SARNAM™ unweighted peak level and measured A-weighted peak level. The data chart presents SARNAM™ calculated peak and three experimental metrics, namely mean, maximum, and minimum peak level as the first four bars on the charts. SARNAM™ calculates the mean expected value of unweighted peak level for each combination of weapon and location for mild downwind conditions and reports the largest. The experimental values on most days are for a variety of weapons and locations, most of which will yield smaller levels that depress the mean peak (and can be skewed by weather effects). It is therefore expected that the SARNAM™ predictions would be higher than the measured mean by a margin dependent on the weapon type and location. Examination of the data for individual days, presented in the companion Final Report (Pater et al., 2007), led to the conclusion that the calculated mean peak was almost always larger than the mean measured peak and smaller than the maximum measured peak that occurred during any day. The same conclusions result from examination of the overall data presented in Figure 5 and Table 1 (with the exception of Site 2). While these results are consistent with physics principles, the predictions do not agree with measured values within the target 5-dB goal. The average disagreement between SARNAM™ calculated peak and the measured mean peak for all days and all sites is about 23 dB. The discrepancy may be due to errors in weapon type or location, to the mix of weapons on each day, or to the weather. These data serve to substantially improve our understanding of how to interpret both calculated and measured small arms blast noise metric values.

Judging validity by comparing single event SEL is less illuminating. SARNAM™ calculates the ASEL that results from one shot. The measured ASEL value during any 1-second measurement period may include several shots. The calculated value reported is the maximum that occurs at a given site for firing noise from potentially several different weapons at several different firing locations. Available data are not sufficient to sort out this situation since it was not reliably known when or where any given weapon was fired; detailed weather effects are unknown in the experimental data; and SARNAM™ does not account for them in calculations. Examination of the data provides little basis for judging software validity.

Comparison of total ASEL is of considerable interest since it is the basis for calculating long-term average noise level metrics such as Leq and DNL. Total ASEL is the aggregate A-weighted sound energy that arrives at a given site. Both the calculated and experimental data in principle should yield the same result. The validity of this comparison is hampered by the uncertain reliability of the range records and the unknown weather effects. After suspect data had been discarded, the data set encompassed data for a total of 83 measurement sites on 23 days. The

difference between calculated and measured ASEL values averaged across all the data was 18.6 dB. This does not meet the performance criterion of 5 dB. While we expected that SARNAM™ overpredicts somewhat (a consequence of a development budget cut), this is a larger discrepancy than was expected.

A partial explanation of this disagreement was discovered after the measurements and data analyses were completed and drafts for both the Final Report (Pater et al., 2007) and the Cost and Performance Report (this document) had been completed and submitted. It was discovered that the microprocessor-based Norsonics 121 noise monitors did not correctly calculate overall (broadband) ASEL values for detected noise events. Fortunately, peak levels and octave band spectral values of unweighted SEL for each event had been measured and recorded, and testing of the instruments indicated that these were correct. The data for about 166,000 noise events were reprocessed to correctly calculate all ASEL values, the new data were re-analyzed, and new tabular and graphical presentations prepared. The noise monitor ASEL calculation error was found to be apparently random, with a mean error of -4.65 dB and a standard deviation of about 1.5 dB. This reduces the average difference between calculated and measured ASEL to about 14 dB.

Reconsideration of SARNAM™ sound level calculation algorithms and procedures confirmed the conclusion that the predictions are accurate for mild downwind conditions. The discrepancy between predictions and measurements may be the result of inaccurate range firing records; accurate input information regarding weapon type, location, and number of rounds fired is a critical requirement for accurate results. A "perfect" study would have the firing ranges operating as controlled environments, which is neither fiscally nor operationally feasible. Another possible contributing factor is that, due to unanticipated closure of the range, no winter firing days were included in the assessment period; noise levels can be expected to be substantially higher in winter than in summer because of refraction caused by prevailing wind and temperature structure in the atmosphere.

It is clear that SARNAM™ could significantly benefit from additional weather classifications to predict both single event levels and average levels more accurately. It would also be highly useful to predict not only the mean level but also some measure of expected statistical variance. A software upgrade is planned to address these needed improvements. The authors also conclude that a noise model validation study of the type undertaken in this project can be conclusive only if all important parameters, including firing event data and atmospheric parameters that affect sound propagation, are measured. As long as SARNAM™ cannot accurately predict received sound level for specific weather conditions, or if specific weather conditions are unknown (for example, when making calculations in the past or future), agreement between measurements and calculations cannot be expected on an absolute scale. SARNAM™ is highly valuable for assessing the effect of changes in range location, physical structure, or operation, for the purpose of reducing noise in the community.

4.3.2   Demonstration Aspects at Camp Ava

The SARNAM™ software application was used in the planning of an MPMG .50 caliber range at Camp Ava. The noise reduction consultation performed for Camp Ava serves to demonstrate the time- and cost-saving benefits and the noise reduction potential of SARNAM™. The actual

name of the installation and actual map features are not used in this demonstration description to avoid revealing facility information that may compromise operational security. The presentation is faithful to meaningful illustration of the noise analysis and results.

Noise impact assessment, as the basis for recommendations for reducing identified impacts, was carried out according to DoD land use and compatibility principles and guidelines. In 1980 the Federal Interagency Committee on Urban Noise (FICUN, 1980) developed land use guidelines, adopted by the DoD, for areas on and/or near noise-producing activities such as highways, airports, and firing ranges. The Army's Installation Noise Management Program (INMP), as well as the other Services' programs, uses the guidelines, which are presented in Table 2. The DA PAM 200-1 (2002) designates noise zones for land use planning. By projecting these zones onto an area map, land use guidelines can help planners develop compatible land uses and reduce noise impacts. The borders of the zones are defined by noise level contours of specific values. Noise level contours should be viewed as indications of the local noise environment, not as the boundary between acceptable and unacceptable noise levels; stepping across the location on the ground of a noise contour does not result in a sudden change in the noise environment. The guidelines, based on long-term average noise exposure levels, are based on a significant body of research results (CHABA, 1981; CHABA, 1996). The guidelines are consistent with the methodology and guidance that is accepted practice for other types of noise such as transportation noise due to aircraft and highway traffic (Schultz, 1978). Because weapon impulse noise can vary so widely due to weather (Schomer and Luz, 1978), average levels can be usefully supplemented by single event levels to more accurately assess community noise impact, particularly regarding the likelihood of receiving noise complaints (Pater, 1976; Hede and Bullen, 1982; Luz et al., 1983; O'Loughlin et al., 1986; Sorenson and Magnusson,1979).

Table 2. Land-Use Planning Guidelines
(DA PAM 200-1, 2002).

Noise Zone (See Appendix A)	Noise Limits			
	Population Highly Annoyed	Transportation ADNL	Impulsive CDNL	Small Arms ADNL
I	< 15 %	< 65 dBA	62 dBC	< 65 dBA
II	15 – 39 %	65 - 75 dBA	62 - 70 dBC	65 - 75 dBA
III	> 39 %	> 75 dBA	> 70 dBC	> 75 dBA

ADNL = A-weighted day-night average sound level
CDNL = C-weighted day-night average sound level
dBA = decibels, A-weighted
dBC = decibels, C-weighted

In March 2003, Camp Ava planned to construct an MPMG range. To assist Camp Ava in the siting of the range to reduce noise impacts on neighboring communities, SARNAM™ was used by USACHPPM to examine alternative range site scenarios. Several range sites and variations in details of the range construction were considered as possible means to reduce the noise levels in the community.

Figure 6 shows the noise zones, calculated by means of SARNAM™, for the installation's initial concept of the new MPMG range. Noise Zone III, which is normally deemed suitable only for land uses such as industry or agriculture that are not highly sensitive to noise, extended off-post.

Noise Zone II, normally not recommended for noise-sensitive land uses, including residential areas, protruded a considerable distance into the community.

An alternative shown in Figure 7 involved moving the range 500 meters east and adding noise barriers. The noise barriers, actually earth berms, also improved range safety. These changes in range location and construction enabled reduction of community noise level by at least 5 dB, and as much as 10 dB in portions of the contiguous community that are located near the installation boundary. This reduction in noise level substantially exceeds the noise reduction goal of 4 to 5 dB.

4.4   TECHNOLOGY COMPARISON

The previous technology for assessment or mitigation of small arms range noise was field measurements supplemented by hand calculations of received noise level. The extreme variability of received noise due to changes in propagation conditions (weather) severely limited the general applicability of measurements. The quality of calculation of received noise level was dependent on knowledge of an esoteric field and on the availability of source models for small weapons. The SARNAM™ software enables consideration of alternate locations of a range and the introduction of noise barriers and safety baffles with relative ease. It also allows for the placement of acoustical absorption materials on barriers and baffles. These modeling features were not previously available. Once the initial input file is created, the SARNAM™ software allows rapid calculation of alternatives. The efficiency of rapid calculation, elimination of human error during calculations, and the extensive set of weapons for which calculations can be easily made represent significant advances in capability.
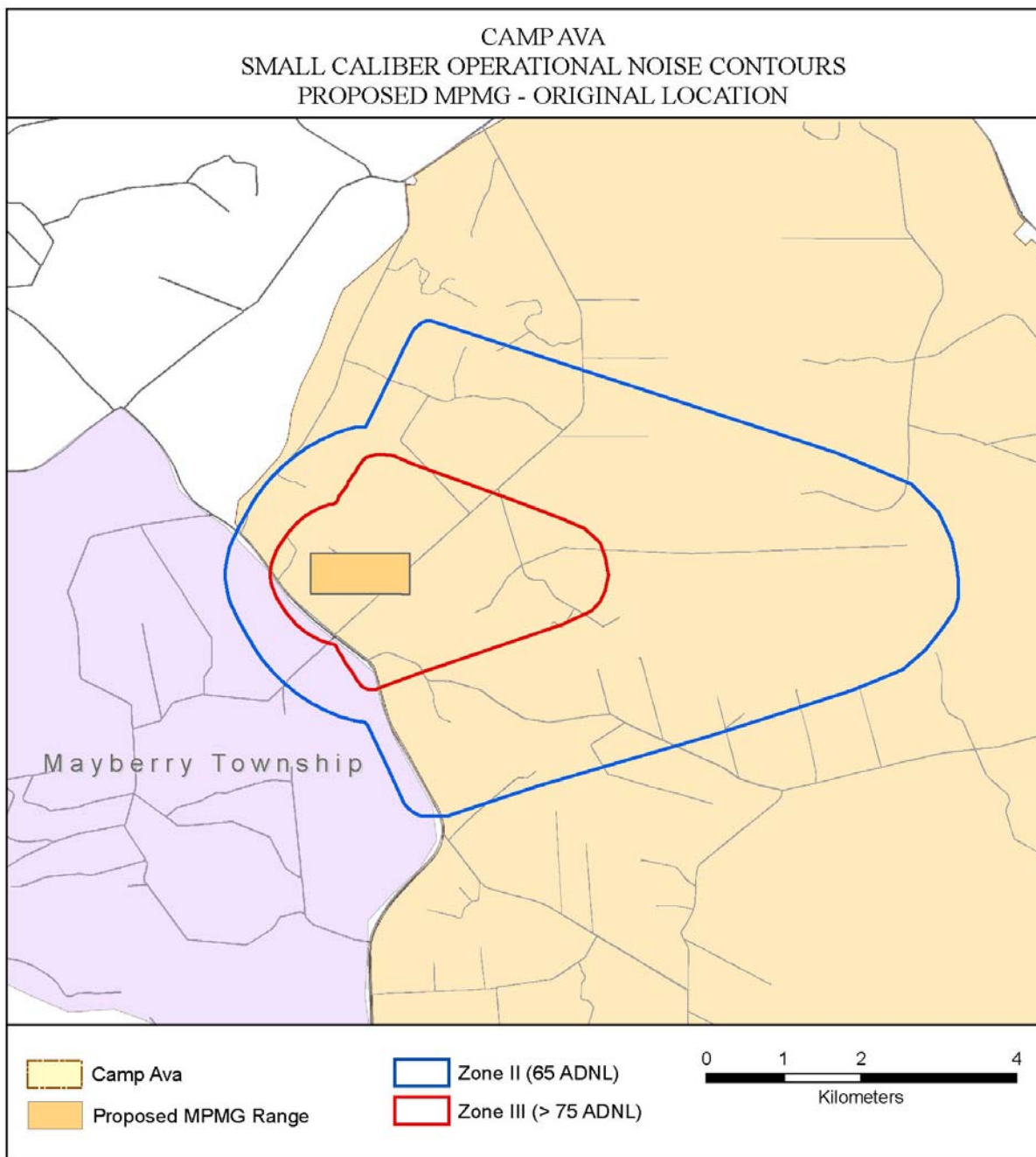
Figure 6. Camp Ava MPMG Firing Range Noise Zones for the Original Range Concept.

**CAMP AVA
SMALL CALIBER OPERATIONAL NOISE CONTOURS
PROPOSED MPMG - RELOCATION 500 METERS EAST WITH BERMS**

Mayberry Township

Camp Ava

Proposed MPMG Range

Zone II (65 ADNL)

Zone III (> 75 ADNL)

0   1   2   4
Kilometers

Figure 7. Camp Ava MPMG Firing Range Noise Zones for the Relocated Range and with the Addition of Noise Barriers.

5.0 COST ASSESSMENT

5.1 COST REPORTING

A quantifiable performance objective of the noise model demonstration is a 20% reduction in overall cost associated with the SARNAM™ software. One consideration is the startup cost of using the SARNAM™ noise software. Another is the cost of using SARNAM™ to perform a noise assessment, compared with the cost of using previous methods that involved modeling done by hand calculations and noise sampling.

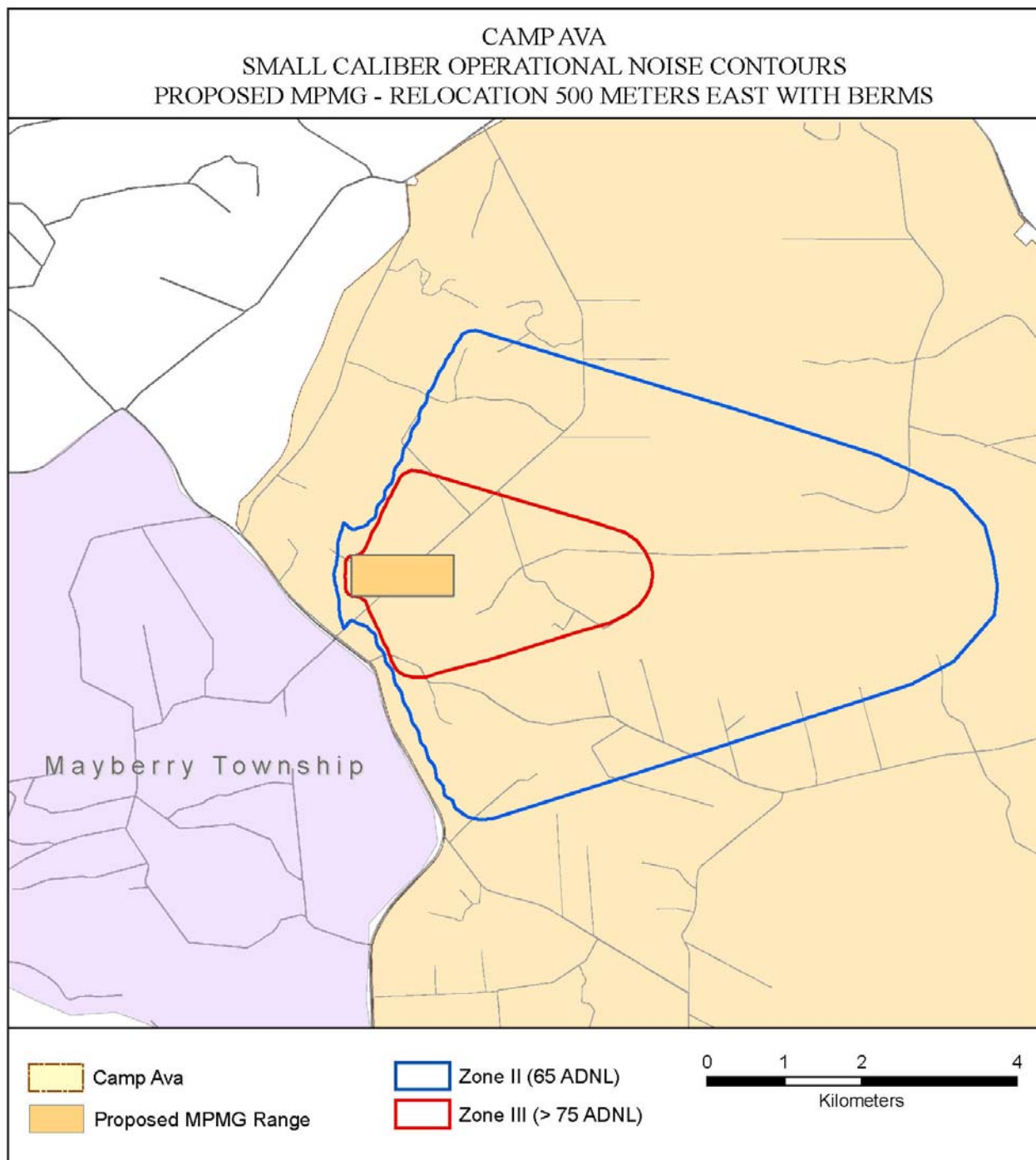Still another consideration is the savings that result from operating a range complex according to recommendations that result from SARNAM™ analysis, compared with the costs of operating without benefit of noise software guidance. Factors include cost considerations associated with damage claims, closure of ranges, land acquisition costs, costs of loss of training days and training acres, and noise complaints. These cost benefits are difficult to evaluate conclusively. An estimate of the cost of training and testing noise to the Army and what cost reduction can be realized through a noise management program based on technology and public outreach is presented in Appendix B. The overall cost of noise to the Army is very large but was not included in this cost assessment. An example of lost training and lost construction funds is the deactivation of a new multimillion dollar small arms range that was sited without a noise assessment and was abandoned and rebuilt in another location because of adverse community reaction to noise. Such large cost savings, plus the desire to be a good neighbor, motivate installations to perform noise impact analysis using the SARNAM™ noise software.

The startup costs associated with using noise software to guide noise management are small. They consist of the cost of an ordinary personal computer, if a suitable one is not already available, and the cost of training the user to use the software. Assuming that the user is familiar with training procedures and the weapons of interest, and has some acoustics knowledge, the cost of the training and familiarization is about 40 hours of labor per user, usually a total of less than $4,000 per user. The SARNAM™ software is provided free of charge.

The above costs occur at the user level, either at the installation, at USACHPPM, or at a contractor site for cases in which the installation itself cannot or does not wish to carry out the noise analysis. In cases where the installation contracts with USACHPPM or with another consultant to carry out noise analyses, the cost will depend on how extensive the required noise impact analysis is; costs can range from nearly zero to as much as $100,000. The cost picture must also include considerations of USACHPPM mission funding leveraging and profit costs of private contractors. Much of the cost of an assessment is obtaining and validating the training data that constitutes the input data for the assessment.

5.2 COST ANALYSIS

The cost analysis is presented here for the assessment that is the subject of the demonstration performance evaluation for Camp Ava. During the NEPA process for placement of the MPMG range, several scenarios were examined to determine the best range location and design for reduced noise impacts on surrounding communities. The demonstration cost was approximately $15,000, which includes report writing and reproduction, as detailed in Table 3.

Table 3. Cost Comparison – Noise Assessment of a Proposed Range.

Previous Method --- On-Site Noise Monitoring*		
	Labor cost	**Man hours**
Preliminary hand calculation of noise levels by project officer	$14,770	200
Equipment maintenance/preparation by technicians	$5,200	160
Equipment supplies and shipping	$913	n/a
On-site monitoring labor		240
Project officer	$5,908	
Technicians	$5,200	
Data analysis by project officer	$5,908	80
Report		
Project officer	$2,954	40
Senior project officer	$1,780	20
Admin	$492	15
Total Cost	$43,125	755
Cost analysis is based on a 2-week on-site monitoring study with one project officer and two technicians. This figure does not include travel expenses, i.e., airfare, hotel, per deim, and rental vehicle.		
Demonstration Method --- SARNAM™		
	Labor cost	**Man hours**
Noise assessment via SARNAM™	$9,914	120
Report		
Project officer	$3,305	40
Senior project officer	$1,780	20
Admin	$492	15
Total Cost	$15,491	195
Total SARNAM™ Cost Savings		
	Labor Cost Savings	**Man-Hour Savings**
	$27,634	560
	64%	74.17%

5.3   COST COMPARISON

The cost comparison presented in Table 3 addresses the cost benefits of using SARNAM™ to perform a specific noise assessment of a proposed range verses the previous method of on-site monitoring and hand calculations. Prior to SARNAM™ the only way to perform noise impact assessment for small arms ranges was by hand calculation of received noise, in conjunction with conducting a minimum 2-week on-site monitoring study, followed by approximately 2 weeks for monitoring data analysis and 1 week for report writing. The Camp Ava project using the pre-SARNAM™/manual methods would have cost $43,125 and 755 man-hours. The use of SARNAM™ reduced the cost by $27,634 or 560 man-hours. The overall savings in costs and man-hours allows USACHPPM to provide faster, more cost-effect service to DoD. This cost reduction amounts to 64%, which easily meets the 20% cost reduction goal.

6.0   IMPLEMENTATION ISSUES

6.1   COST OBSERVATIONS

SARNAM™ will reduce the resources needed to predict the noise from existing and proposed ranges throughout DoD. It will reduce the cost to assess noise impacts and examine alternative scenarios for both testing and training range operations and planning by more than 20%. The cost benefits of maintaining viable training capability in the face of encroachment of a population that is increasingly less tolerant of degradation of their living environment are huge.

6.2   PERFORMANCE OBSERVATIONS

The absolute accuracy of SARNAM™ noise predictions remains unproven, and in any case, is to some extent not of primary interest, given the large variance in received noise level due to weather conditions and the lack of noise laws that limit noise levels. The most important use of SARNAM™ is noise management by striking a balance between mission execution and environmental quality. Reliable guidance regarding noise level reduction under a wide range of conditions is arguably more important than the absolute accuracy of noise level predictions for specific conditions.

6.3   OTHER SIGNIFICANT OBSERVATIONS

SARNAM™ gives the DoD, public law enforcement agencies, and the private sector, a tool for noise management from small arms ranges that was not previously available.

6.4   LESSONS LEARNED

This project provided the first opportunity to test SARNAM™ exhaustively and in detail for accuracy and performance in assessing training noise impact under conditions of actual training at an installation over a protracted time period. The utility of the software for noise mitigation was demonstrated. An extremely favorable cost performance was also shown. The project revealed the extreme importance of reliable training activity data, particularly regarding the type of weapons and the number of rounds fired on each range throughout the assessment period. The noise monitor measurements showed the extreme variability of received noise level. The lack of agreement between calculated and measured noise levels caused the researchers to conclude that there is the need to modify SARNAM™ to offer the user a selection of weather conditions. This has been done for two other blast noise models and was intended for SARNAM™ but was prevented by development budget cuts. SARNAM™ remains the only software package available to calculate and display weapons noise contours due to weapons impulsive noise, which greatly facilitates assessment of noise impacts and evaluation of noise mitigation options. Results of this project will guide improvement of current and new noise impact assessment software. Results of this study are also of value for guiding how the DoD conducts noise impact assessment. The difficulty of obtaining accurate data for the number of rounds fired means that average noise metric values are of dubious accuracy; this is one reason for using single event metric noise levels, since weapon type and location are comparatively easy to ascertain accurately. This project will result in improvement in noise assessment software and procedures that will contribute to sustainable training capability. The project confirmed the fast that the most

important purpose of a noise model such as SARNAM™ is not to predict the absolute noise level in the community but to serve as a mitigation tool to manage noise disturbance and environmental quality.

6.5   END-USER ISSUES

The primary end user is USACHPPM; others include contractors who perform noise assessments for installations and installation personnel, including master planners, trainers, and range operators. All of them are concerned about the accuracy of the software, cost, and ease of use. The software runs on common personal computers that utilize the Windows™ operating system. The demonstration/validation project used commercially available noise monitoring equipment. The Army developed the SARNAM™ software and hence there are no proprietary considerations. Noise emission depends strongly on the type of weapons fired, which is dictated by training requirements. The noise dose in the community can be influenced by other controllable factors, particularly the location of the firing, the design and orientation of the range, the time and weather conditions when the firing occurs, and the number of noise events.

6.6   APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

There are no national regulations regarding weapons blast noise. Current "regulation" amounts to self-regulation by the installation to maintain noise at levels acceptable to community residents. This is done by a combination of technology, planning, and public outreach. Information generated by SARNAM™ is used by USACHPPM in consultation with installations to minimize noise problems and is available to the installations and the public. Noise models such as SARNAM™ have been formally integrated into Huntsville range design manuals.

SARNAM™ is optimally used as an environmental planning tool to address unwanted noise as an environmental attribute in the community at large rather than a regulatory compliance tool since there are no legally binding criteria for human exposure to noise that support "compliance" levels outside the facility perimeter. Calculated noise contours are used as planning tools for land use guidelines. SARNAM™ can be used to avoid siting new noise-sensitive land uses in off-post areas impacted by military noise as well as to plan military facilities and operations to minimize community noise levels.

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APPENDIX A

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APPENDIX B

GLOSSARY OF TERMS

A-Weighted Sound Level – The ear does not respond equally to sounds of all frequencies but is less efficient at low and high frequencies than it is at medium or speech range frequencies. Thus, to obtain a single number representing the sound pressure level of a noise containing a wide range of frequencies in a manner approximating the response of the ear, it is necessary to reduce, or weight, the effects of the low and high frequencies with respect to the medium frequencies. Thus, the low and high frequencies are de-emphasized with the A-weighting.

The A-scale sound level is a quantity, in decibels, read from a standard sound-level meter with A-weighting circuitry. The A-scale weighting discriminates against the lower frequencies according to a relationship approximating the auditory sensitivity of the human ear. The A-scale sound level measures approximately the relative "noisiness" or "annoyance" of many common sounds.

Community – Community means those individuals, organizations, or special interest groups affected by or interested in decisions affecting towns, cities, or unincorporated areas near or adjoining a military installation; and officials of local, state, and federal governments and of Native American tribal councils responsible for decision making and administration of programs affecting those communities.

Day-Night Average Sound Level (DNL) – The 24-hour average frequency-weighted sound level, in decibels, from midnight to midnight, obtained after addition of 10 decibels to sound levels in the night from midnight to 7 a.m. and from 10 p.m. to midnight (0000 to 0700 and 2200 to 2400 hours). A-Weighting is understood unless otherwise specified.

Decibels (dB) – The decibel is a logarithmic unit of measure of sound pressure.

Demonstration – For the purposes of this report, demonstration refers to the use of computer software to calculate and display noise contour. Demonstration did not include field monitoring.

Equivalent Continuous Noise Level (Leq) – The level of a constant sound which, in a given situation and time period, has the same energy as does a time varying sound. For noise sources, which are not in continuous operation, the equivalent sound level may be obtained by summing individual sound exposure level (SEL) values and normalizing over the appropriate time period.

Frequency – Number of complete oscillation cycles per unit of time. The unit of frequency is the Hertz.

Hertz – Unit of frequency equal to one cycle per second.

Impulse Noise (Impulsive Noise) – Noise of short duration (typically less than 1 second), especially of high intensity, abrupt onset, rapid decay, and often rapidly changing spectral composition. Impulse noise is characteristically associated with such sources as explosions,

impacts, the discharge of firearms, the passage of supersonic aircraft (sonic boom), and many industrial processes.

Noise – Sound deemed by an observer to be annoying, objectionable, or without value.

Noise Exposure – The cumulative acoustic stimulation reaching the ear of a person over a specified period of time (e.g., a work shift, a day, or a lifetime).

Noise Zone III – Noise Zone III consists of the area around the noise source in which the level is greater than 70 dB C-weighted day-night average sound level (CDNL) for large caliber weapons or greater than 75 dB A-weighted day-night average sound level (ADNL) for small caliber weapons. Noise-sensitive land uses (such as housing, schools, and medical facilities) are not recommended within Noise Zone III.

Noise Zone II – Noise Zone II consists of an area where the DNL is between 62 and 70 dB CDNL for large caliber weapons or between 65 and 75 dB ADNL for small caliber weapons. Land within Noise Zone II should normally be limited to activities such as industrial, manufacturing, transportation, and resource production. However, if the community determines that land in Noise Zone II (attributable to small arms) areas must be used for residential purposes, then noise level reduction (NLR) features of 25 to 30 decibels should be incorporated into the design and construction of new buildings to mitigate noise levels. For large caliber weapons, NLR features cannot adequately mitigate the low-frequency component of large caliber weapons noise.

Noise Zone I – Noise Zone I includes all areas around a noise source in which the day-night sound level is less than 62 dB CDNL for large caliber weapons and less than 65 ADNL for small arms weapons. This area is usually acceptable for all types of land use activities.

Sound Exposure (SE) – The integral of sound pressure squared integrated over a specified time period.

Sound Exposure Level (SEL) – Defined as 10 times the base 10 logarithm of a quantity consisting of the sound exposure divided by an appropriate standardized reference quantity.

Validation – For the purposes of this report, validation refers to the field monitoring performed at Marseilles Training Site.

APPENDIX C

NOISE COSTS TO THE ARMY

This analysis provides an estimate of the impact of training and testing noise on DoD operating budgets. Not all of these costs can be addressed through use of noise assessment software, and the benefit directly attributable to SARNAM™ would be highly dependent on the situation.

This cost analysis addresses noise types that are Army-unique, and will not receive adequate attention if DoD does not address them. These noise types are helicopter, blast (artillery, armor, detonations), and small arms noise. The cost of dealing with the effects of noise on threatened and endangered species is included here since the assessment of such effects relies heavily on the tools and technology developed by the Army noise research and development (R&D) program. Effects of noise on domestic animals are also included here, in damage claims. Costs are calculated based on damage claims, complaint handling, range and firing point closures, NEPA and ONMP assessment costs, acquisition of new land, and impact on training and testing capability. Training and testing capability impacts include loss of training hours and loss of use of training acres, rescheduling training and testing, modifying training procedures, and the consequences of inadequate training. All costs are estimated in terms of FY03 dollar value, not adjusted for inflation.

DAMAGE CLAIMS. Each year, damage claims directly attributable to noise, with a total value of about $16 million, are submitted to the Army Claims Service (ACS). About $0.25 million are paid each year by the ACS. This does not include claims smaller than $25,000, which are handled locally. It is estimated that total damage claims that are paid Army-wide amount to about $900,000 per year. This does not include the processing cost, estimated to average about 60 man-hours which at $63/hr equals $3,780 each. If the total number of claims is estimated to be 800 claims per year, the estimated processing cost is approximately $3 million. Thus the total cost of damage claims is about $3.9 million per year. With improved technology, better tech transfer, and better coordination via a user group, it is estimated that this cost could be reduced by 20%. Without a noise program, there would be a lack of information regarding validity of noise damage claims, many invalid claims would be paid, and valid ones would be denied and would lead to expensive litigation. The cost could rapidly escalate.

COMPLAINT HANDLING. Haphazard handling of complaints results in damaged community relations, which results in escalated complaints and many more resources and man-hours spent dealing with the consequences. The time per complaint in the aggregate can easily amount to 30 man-hours which at $63/hr equals $1,890. A typical installation may receive 30 complaints per year. This occurs at perhaps 100 installations, including ARNG. Thus the total annual cost can be evaluated as $1,890 x 30 x 100 equals approximately $5.7 million. Improved methods, using a tested complaint management system based on experience and disseminated via improved technology transfer, can reduce costs by an estimated 20%. Each complaint can be handled more efficiently and more appropriately, avoiding escalation. Without the program and without effective technology transfer the losses would grow with time as more planning and design mistakes accumulate and result in more complaints.

RANGE CLOSURE. Ranges have been closed and use of firing points discontinued because of noise. A $19 million range in Wielflecken, Germany, and a $3 million small arms range at Camp Butner, North Carolina, are examples in the past several years. If it is estimated that a range is closed on average once every two years and must be replaced at an average cost of $10.6 million, one arrives at an annual cost of $5.3 million. Firing points cost about $325,000 to plan and construct. An estimated loss of 10 firing points per year equals $3.25 million. The total cost of losing the use of ranges and firing points is thus estimated to be $8.55 million annually. This loss could be reduced by an estimated 20% by proper siting and design of new ranges and by improved management of existing ranges. Without the program, without effective technology transfer, and without a user group to help disseminate information and technology and lessons learned, losses would grow with time as more planning, design and operations management mistakes accumulate, resulting in the closure of more ranges and firing points.

LAND ACQUISITION AND ENCROACHMENT. Land is often acquired to mitigate severe noise problems. Assume land to have an average value (improved and unimproved) of $6,400 (range of $1,000 to $150,000) per acre. Most land acquisitions are motivated by several factors; the most common are noise and TES. Fifty percent of land acquisition cost is attributed to noise. Many erroneously believe that the military does not currently acquire land. In fact, the Army, Marine Corps, and National Guard acquire more than 2,500 acres per year. Recent examples include Camp Dodge, Iowa; Fort Polk, Louisiana; Fort Campbell, Kentucky (130 acres near the Sabre Army Heliport); and Fort Bragg/Pope Air Force Base, North Carolina, near Simmons Army Airfield (100 acres and 10,000 acres, respectively). Other installations are considering substantial land acquisitions to avoid encroachment and accompanying noise problems; at least one of these may amount to as much as $150 million. Using the smaller, concrete figures, one calculates that 2,500 x $6,400 x .5 equals $8 million annually. With improved methods of noise management, the cost of land acquisition could be decreased. If one assumes that improved noise management and mitigation technology could reduce noise motivation for land acquisition by 20%, one arrives at an overall reduction of about 10%, or $800,000 per year. Without the noise program, the situation could become much worse. Much more land would be acquired in an attempt to mitigate noise problems.

NEPA AND ONMP ASSESSMENT. The ONMP is mandated by Army Regulation (AR)200-1. The NEPA Environmental Assessment (EA) and Environmental Impact Statement (EIS) procedures usually show noise to be a leading issue. ERDC/CERL and USACHPPM get many phone calls each year asking for help on these problems. Noise dose assessment software such as NOISEMAP, BNOISE2™ and SARNAM™ are essential to assess impacts. A typical ONMP study costs about $50,000, and is redone about every 5 years. Significant ONMP studies are done at about 75 installations, for an annual cost of $50,000 x 75/5 equaling $750,000. A typical NEPA study costs $2.2 million, about 10% of which can typically be attributed to noise. Such a study is typically needed about every 4 years, at perhaps 100 installations. A cost estimate is thus $2.2 million/4 x .1 x 100 equals $5.5 million. Total annual cost of preparing the required reports is thus estimated to be $7.9 million. This does not include the cost of staff time required to shepherd an ONMP, EA, or EIS through the multiyear process from conception to completion. Assume a man-year of labor costs at about $106,000. An average ONMP requires perhaps 1/2 man-year of installation staff time, a cost of $53,000. An average EA or EIS typically requires much more effort, perhaps a total of three man-years, cost $318,000. The staff cost attributable to

noise is thus estimated to be $53,000 \times 75/5$ + NEPA $318,000/4 \times .1 \times 100$ equals $1.6 million. Total annual cost is thus approximately $7.8 million. With improved technology and transfer of same, including to private contractors who often execute these studies, and to installations so they can be smart buyers, costs can be reduced by at least 20%. Without the program, current tools will quickly become obsolete as new weapons are introduced and as adversaries demand the use of modern sophisticated technology. Calculation of noise contours for installations' noisy operations demands automated calculation tools because of complexity and computational labor. Without such tools, NEPA and ONMP would be unsatisfactory. The consequences are substantial and would grow with time.

REDUCED TRAINING CAPABILITY. Noise insidiously compromises training by preventing some types of training from being carried out because of noise impacts or because of loss of training facilities. An inadequately trained soldier is at risk, and his combat mission is also put at risk. Estimating the dollar cost of the death of a soldier is problematic. Estimating the cost of not achieving a combat objective could be extremely large but is also difficult to estimate accurately. To maintain credibility, this estimate is based strictly on the cost of loss of training hours, rescheduling training, and modifying training procedures. An hour of training, for each trainee, including range O&M, support personnel, and equipment, is estimated to cost $110. Total training of 500,000 troops (U.S. Army, U. S. Army Reserve, ARNG, and U.S. Marine Corps) may involve on the average 100 hours of noisy training per trainee per year. Such training occurs on at least 45 installations (10 U.S. Army Forces Command, 10 U.S. Army Training and Doctrine Command, eight ARNG, five U.S. Army Materiel Command, and 12 Navy/USMC/U.S. Air Force). The total cost of such noisy training can be estimated thus: $500,000 \times 100$ hrs $\times$ $110 = $5.5 billion. Conservatively, if only 5% of this noisy training is compromised by noise impacts, the cost is $275 million. Testing is often canceled or rescheduled because of possible noise impacts. This is expensive because many dedicated labor costs continue whether or not testing is carried out. It is estimated that these costs are about $3,300 per hour at a typical testing range such as Aberdeen Proving Ground, Maryland, or Yuma Proving Ground, Arizona, and that a total of at least 1,000 hours of such costs are experienced each year Army-wide, for an additional cost of $3.3 million. Additional hidden costs, particularly transportation costs, accrue due to relocation of testing because of noise. These costs easily amount to an average of $200 per troop each year, for a total of $500,000 \times $200, which equals $100 million. The total cost of reduced training capability due to noise is thus estimated to be $378 million per year. With improved noise management, the loss of training hours, and thus the associated monetary loss, can be substantially reduced by an estimated 20%. Without noise management technology, the impacts of noise on training capability would rapidly grow.

SUMMARY and COST AVOIDANCE: The annual costs of noise problems that result from the response of humans to loud training noise, as estimated in detail above, total to approximately $412 million per year without accounting for the possible cost of loss of life or unachieved combat objectives. During the period of FY06-FY11, this is a total cost of $2.482 billion (FY03 $). A 20% reduction in cost, which is realizable by applying noise tools and technology in combination with a proactive public relations effort, is a cost avoidance of about $492 million.

THREATENED AND ENDANGERED SPECIES SAVINGS: Another problem that endangers training capability is impacts and considerations due to the presence of threatened and

endangered species (TES) on military lands. Under the Endangered Species Act, regulators are charged by law with responsibility to protect TES. In the absence of definitive data regarding the impact of military activity on TES, regulators can make, and indeed have made, decisions that reduce availability of training land. A separate, detailed estimate of the costs associated with the presence of TES on Army lands and the cost avoidance affected by TES impacts on R&D show annual cost avoidance during the period FY06-11 of about $74 million. Noise is one of three stimuli of concern for TES. Since the assessment of noise impacts on TES relies heavily on the tools, techniques, and technology developed by the noise R&D program and is essential to mitigating TES impacts on training capability, it is reasonable to claim 33% of the TES cost avoidance as a benefit of the noise research. Thus additional cost avoidance amounts to an average annual cost of $24 million during the period of FY06-11.

NET COST AVOIDANCE: The total cost avoidance resulting from the Environmental Technology Management Plan (ETMP) program of research, development, and implementation of noise tools, techniques, and technology during the period FY06-11 is thus about $516 million, expressed in FY03 dollars. The total cost of the noise program is about $32 million in FY01 dollars, thus indicating a significant return on investment.

Noise Cost Avoidance Worksheet (FY03 $)

Category	Annual Cost ($K)	Cost Avoidance Annual ($K)	Cost Avoidance FY 06-11 Total ($K)
Damage claims	3,924	785	4,709
Complaints	5,670	1,134	6,804
Range closure	8,550	1,710	10,260
Encroachment	8,000	800	4,800
NEPA/ONMP	7,840	1,898	9,738
Reduced training capability	378,000	75,600	453,600
Compliance Noise Total	411,984	81,927	489,911
TES Savings (source: TES ETMP)	20,583	4,117	24,700
NET COST AVOIDANCE	432,567	86,043	514,611

INTANGIBLE BENEFITS: An important aspect of encroachment-related noise problems is that it may not be feasible to replace training lands, simply because suitable lands are not available at any price to create a new training facility equivalent to installations such as Fort Carson, Fort Hood, Fort Lewis, Fort Stewart, and Fort Benning. Thus, a great value of intelligent noise management is sustaining training capability on existing training lands.

Noise management also produces qualitative benefits. Lower noise levels will result in improved quality of life for both Army personnel and the residents of the region surrounding Army and National Guard installations. Fewer noise problems help to ensure that Army personnel are well-trained, will remain in the Army, and will be able to carry out combat missions with greater effectiveness and reduced losses. An effective and proactive noise management program greatly improves relations with the surrounding community.

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